TEMPERATURE AND FLOW RATE EFFECTS ON MASS MEDIAN DIAMETERS OF THERMALLY GENERATED MALATHION AND NALED FOGS[1]

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ABSTRACT. The effects of temperature and flow rate on mass median diameters (mmds) of thermally generated aerosol clouds were studied. Number 2 fuel oil alone, undiluted and diluted malathion 91, and undiluted naled were examined. There was a significant flow rate × temperature interaction on the mmds of diluted malathion fogs: i.e., differences among flow rates depended on temperature and vice versa.

With the advent of cold aerosol ultra-low volume (ULV) technology 2 decades ago, research in thermal aerosols declined in the USA. However, thermal aerosols are still an important control technology in other portions of the world. For instance, in 1990, more than 80% of Lowndes Engineering, Inc. (Valdosta, GA 31601) and TIFA® (Millington, NJ 07946) thermal fog sales were to India and the Middle East (Lowndes Engineering and TIFA, personal communication). Flow rates up to 151.5 liters per hour were used in the mosquito control industry 2 1/2 decades ago when the costs of fuel oil and pesticides were substantially less than at present. Future application for those organizations intent on utilizing thermal fog should be designed to conserve or reduce costly fuel oil. Table 1 indicates current costs per mile of thermal fogging in the SE United States and Barbados, West Indies. One alternative is the operation of thermal fog equipment at lower flow rates. However, since the inception of cold aerosol ULV generators in the mid-1960s and the work of Rathburn et al. (1965), little information has been in the literature indicating efficacy of reduced thermal aerosol insecticide rates for mosquito control.

The objectives for this work were: 1) Determine the mass median diameters of malathion and naled produced by a thermal generator. 2) Determine the relationship between: flow rates of No. 2 fuel oil, malathion diluted with No. 2 fuel oil and undiluted malathion and naled with combustion chamber temperatures in regard to aerosol droplet size.

[1] The opinions and assertions contained herein are the private ones of the writers and are not to be construed as official or reflecting the views of the Navy Department, the Naval Service at large or the USDA-ARS.

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The thermal fogger used was a stationary Leco® 120D (Lowndes Engineering, Inc.). Standard Leco orifices were used at all flow rates of ≥45.5 liters per hour. An FMI laboratory pump (Fluid Metering, Inc., Oyster Bay, NY 11771) was connected directly to the heater and was used to deliver the ≤45.5 liters per hour rates.

Droplets were collected on Teflon® coated slides waved in a vertical fashion from 0.6 m in height through the aerosol cloud to approximately 2.7 m in height and 8.0 m from the nozzle opening (Brown et al. 1990). Collections were made when ambient temperature were 21.1–35°C. After collection, glass slides were sealed in a slide box and 100 drops per slide measured within 4 hours.

Tests were conducted with undiluted No. 2 fuel oil, undiluted malathion 91, malathion 91 at 46.8 ml per liter of No. 2 fuel oil, and naled at 7.8 ml per liter of No. 2 fuel oil. Temperatures utilized were 288, 399 and 510°C for the fuel oil alone; 121, 288 and 510°C for malathion diluted with No. 2 fuel oil; and 121, 288, 399 and 510°C for the undiluted naled and malathion. These particular temperatures were selected based on the operating characteristics of the Leco 120D. The effect of machine operating pressures was examined at 12 and 17 psi (Table 2). These settings generally represented low and high limits on machine operating pressures.

Droplet analysis was performed using the VECTEC droplet analysis program (VECTEC, Orlando, FL 32807). Analysis of variance was performed on the mass median diameters of malathion and naled using the SAS GLM procedure (SAS User's Guide 1982).

No. 2 Fuel Oil: A mmd increase from 14.1 to 18.1 microns was demonstrated as flow rate (over all temperatures and pressures) was increased from 44.4 to 108 liters per hour. Little difference occurred in mmd due to temperature averaged over machine pressure alone (Table 2). Also, given any flow rate between 44.4 and 108 liters per hour, increasing the temperature alone over the 222°C range had little effect on mmd. It appears that the thermofogger was producing

Table 1. Relative costs per mile of thermal fog applications in the SE United States and Barbados, West Indies.

Location	Price ($) per liter: Naled	Price ($) per liter: Malathion	Price ($) per liter: Fuel oil	Rate[2] (liters/hour)	Price ($) per mile[2]: Naled	Price ($) per mile[2]: Malathion
Florida	16.63	5.81	0.26	302	11.84	16.72
				151	5.92	8.36
				45	1.78	2.51
Barbados[3]	—	4.80	0.22	302	—	14.16
				151	—	7.08
				15	—	2.12

[1] Leco® 120D, standard orifices, Lowndes Engineering, Inc., Valdosta, GA 31601.
[2] Calculations (example):
Max label rate @ 302.8 liters @ 16 km/hour
$48.78 = 1 liter Dibrom
99.00 = 375 liters fuel oil
$147.79 = cost for 378 liters of fog mix according to label instructions to mix 2.9 liters of Dibrom in 375 liters of fuel oil.
$137.79 = $1.48/3.785 liters of fog mix

$$\frac{\text{302 liters/h @ 10 mph \$1.48/3.785 liters cost of Dibrom 14 and fuel oil mix}}{\text{10 miles}} = \$11.81/\text{mile}.$$

[3] WHO-PAHO, Caribbean Program, Bridgetown, Barbados, W.I.

Table 2. Effect of temperature and flow rate on thermal aerosol mass median diameters ± SE of No. 2 fuel oil alone.

Machine pressure (psi)	Heater temperature	Flow rate (liters/hour): 44.4[1]	72.0	108.0	$\bar{x}$
12	288	14.2 ± 1.1[2]	17.5 ± 0.8	16.3 ± 1.7	16.0
	399	14.0 ± 0.4	13.3 ± 0.3	15.3 ± 0.6	14.2
	510	14.1 ± 0.5	17.8 ± 0.5	13.7 ± 1.6	15.2
	$\bar{x}$	14.1	16.2	15.1	
		Flow rate (liters/hour): 46.8	78.6	108.0	
17	288	15.9 ± 0.2	19.5 ± 2.8	18.2 ± 1.0	17.9
	399	15.2 ± 0.9	16.8 ± 0.5	18.1 ± 2.4	16.7
	510	15.3 ± 0.3	15.4 ± 0.5	18.0 ± 1.4	16.2
	$\bar{x}$	15.5	17.2	18.1	

[1] Engine rpm 2,500.
[2] Means of 3 replications.

Table 3. Effect of temperature[1] and flow rate on mass median diameters (microns ± SE) of malathion and No. 2 diesel fuel.[2]

Temp (°C)	Orifice flow rates (liters/hour): 3.2	10.6	21.1	$\bar{x}$
121	16.4 ± 3.6	27.3 ± 6.2	43.3 ± 4.9	29.0
288	9.2 ± 0.6	11.7 ± 1.3	22.3 ± 4.4	14.4
510	11.5 ± 0.9	13.5 ± 1.7	12.6 ± 1.1	12.5
$\bar{x}$	12.4	17.5	26.1	

[1] 399 was not included as in the previous test.
[2] 5 fl oz per 5 gal No. 2 diesel fuel. Three replications.

few large droplets because the flow rate was reduced such that the available volume of heat vaporized more of the liquid (C.B. Rathburn, unpublished data).

Diluted insecticides: There were significant differences ($P = 0.05$) in mmd among the temperatures and flow rates (Table 3). Mmds decreased from 29.0 to 12.5 microns as temperature was increased from 121 to 510°C. Mmds increased from 12.4 to 26.1 microns as flow rates were increased from 3.2 to 21.1 liters per hour. Again, it is suggested that the increase in temperature vaporized most of the liquid and fewer large droplets were produced. Whereas, at the

Table 4. Effect of temperature and flow rate on thermal aerosol mass median diameters (microns ± SE) of undiluted malathion.[1]

Temp. (°C)	Flow rates (liters/hour) Naled 1.8[2]	Malathion 3.22[2]	7.1[2]	14.2[2]
121	—	22.1	13.1 ± 0.5	14.4 ± 0.9
288	11.7 ± 2.3	12.4 ± 0.6	10.4 ± 0.3	11.0 ± 0.8
399	—	18.1 ± 0.6	7.2 ± 0.1	13.1 ± 0.7
510	9.3 ± 1.6	16.1 ± 1.3	<2.5[4]	2.5[4]

[1] Three replications.
[2] FMI laboratory pump.
[3] Leco orifice.
[4] At 400× all droplets observed on slides were ≤2.5 microns.

higher flow rate and low temperature large drops are produced.

Undiluted insecticides: Undiluted naled was examined at 121°C but all 9 slides examined produced droplets too large to be measured (no or little vaporization). Droplet analysis results for undiluted naled at 288 and 510°C were 11.7 ± 2.3 and 9.3 ± 1.6 microns, respectively. Here, the flow rate, combined with sufficient hot air volume, generated few large droplets. This was also the case with undiluted malathion (Table 4). At 510°C and the 2 high flow rates, the heat was sufficient to vaporize most of the liquid volume.

Thorough pesticide efficacy tests are required to fully support this work on flow rates and temperature effects on mass median diameters of thermally generated aerosol clouds. However, these droplet analysis data are potentially useful to those organizations, mostly outside the United States, interested in decreasing flow rates, and thereby costs, when utilizing current thermal fog technology in their mosquito control programs. These data show that a temperature change of 222°C has little effect on naled mmd (Table 4). At the flow rate used in these tests, there was sufficient volume of hot air to vaporize most of the insecticide and very few large droplets were produced. Whereas, a combination of high flow rate (10.6 and 21.1 liters per hour) and insufficient hot air volume (121°C) (Table 3) results in a malathion mmd that exceeds the label mmd recommendations (17 microns). The trend shown by these data indicates that reducing flow rates while maintaining a temperature of ≥288°C will result in an acceptable mmd for malathion.

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